Preprint
UCRL-JC-146947

National Ignition Facility Beamline Pupil Relay Plane Locations and Imaging

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This article was submitted to International Optical Design Conference, Tucson, Arizona, June 3-7, 2002

July 29, 2002

UCRL-JC-146947

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Abstract: Axial astigmatism can be introduced into the nominal design of an optical system by tilted and tilted-wedged plates. The pupil images in the National Ignition Facility experience many such components. Some ramifications will be explored.

OCIS codes: (140.0140) Lasers and laser optics; (120.4820) Optical Systems

Introduction

Laser physicists are sensitive to Relay Plane (RP) locations in the National Ignition Facility (NIF) because of propagation-induced intensity modulation (PIIM) that occurs away from the near-field (NF) images of the RPs. Care was taken in the initial design of NIF to locate the images of RPs to mitigate having any PIIM occurring on optical surfaces which might cause physical damage to the optical coating, optical surface, or internal to the optic. An added complication to this situation is that high-energy beam propagation can shift the effective locations of the RPs away from the "ray traced" locations.

Specifying the Relay Plane Location

The RPs in NIF are imaged from one location to another in a beamline to be at specific locations. These locations were initially determined paraxially with first-order optical retracing. Many of these locations were set prior to the design and insertion in the beamline of polarizers and Faraday rotator plates, and, in some cases, amplifier slabs. The physical thickness of these plates has an impact on the paraxial location of the RPs (see Figure 1). These changes can be mitigated with pathlength adjustments in the subsystems or design of the relay telescopes (RTs), if the plates are part of the lens design requirement.

An added wrinkle to reimaging of the RPs in the long beamline path is that the polarizers, "flat" beamsplitters, and Faraday rotator crystals are tilted relative to the RP imaging, i.e., convergent/divergent imaging beams going through tilted components. Imaging through tilted plates results in astigmatism on axis (see Figure 1). Axial astigmatism results in orientation-dependent focal locations of the RP.

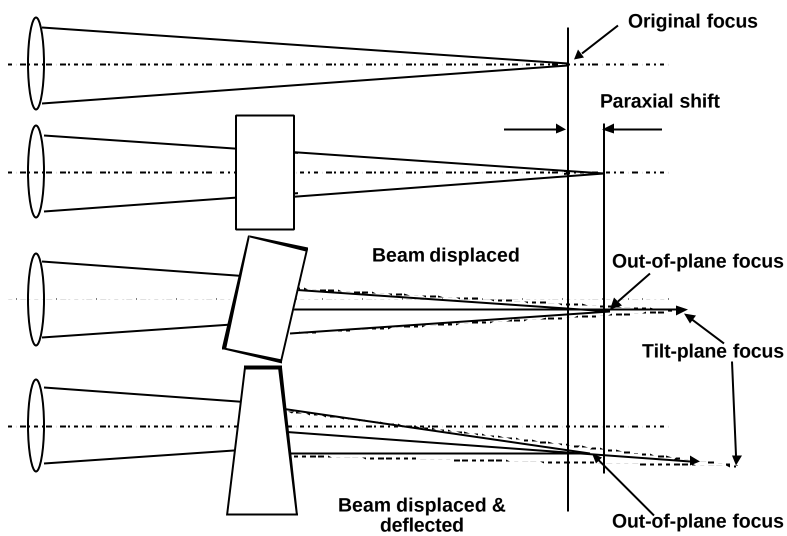


Fig. 1. Focus impact for various components in a focusing beam

However, plane parallel plates can induce Etalon-effect intensity modulations in the beam, so many of the plane parallel plates in NIF are actually slightly wedged in both transmissive and reflective cases. Wedged plates (prisms) in convergent/divergent imaging light also introduces axial astigmatism in the imaging of the RPs. The amount of astigmatism contributed to the imaging depends on several factors, but it is also dependent on the RP distance and the orientation of the wedge in the imaging cone. Some tilted-wedged plates have wedges in the tilt plane and others have the wedge in the plane opposite that of the tilt. The whole collection of tilted and tilted-wedged plates in NIF is a very complex situation creating axial astigmatism in the process of reimaging the individual RPs.

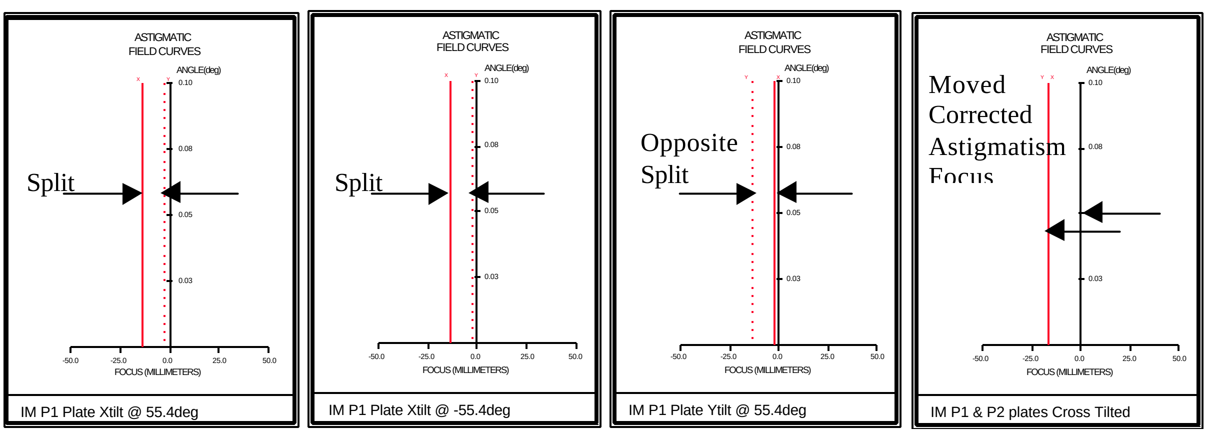
When these asymmetric components are taken into account, there are several different effects to consider: paraxial image location longitudinal shift, lateral beam displacement (AKA Snell walk), beam deflection, as well as the axial astigmatism mentioned above.

A plane parallel plate in an imaging space (where the beam is not collimated) shifts the paraxial image longitudinally. A single tilted plane parallel plate not only longitudinally displaces the image but also introduces Snell walk and axial astigmatism (Figures 2a, 2b, & 2c). Counter tilted identical plates in opposite planes can correct the axial astigmatism (see Figure 2d), but a set of four plates is needed to correct the Snell walk. Tilted-wedged components add an additional amount of axial astigmatism where the astigmatism amount is dependent on how far the RP is from the component (Figure 3). NIF has many tilted plane parallel plates and tilted-wedged components and the beam passes through some of them multiple times making for a complex situation for stating the locations of the RPs. Since paraxial results ignore tilted or tilted wedged pate effects, a better method is needed to specify the NIF RP locations using real rays.

Because of the axial astigmatism has to be considered when specifying the RP location, there are several ways of stipulating the location of a RP based on real-ray tracing.

1. Select the YZ focus – see Figure 2a and 2b, for example which shows tilt independence on sign
2. Select the XZ focus – see Figure 2c
3. Select the midpoint between the XZ and YZ foci
4. Consider the impact of the field impact on the location of the RP image, i.e., use one of the RP edge sides

Since NIF will use the center of cross hairs to judge position, the real-ray midpoint was chosen.



2a 2b 2c 2d

Fig. 2. Real-ray computed axial astigmatism cases

Subsystem optical models can only provide information within a subsystem. Individual models cannot easily provide cumulative effect for a whole beamline. An End-to-End optical model of a NIF beamline has been developed and was used to evaluate the axial astigmatism at the various RP locations.

Relay Plane Solution

Another NIF guiding design principle is to place an RP at the location of the deformable mirror in the system. Having a consistent definition and method of characterizing the RP location with real rays is important to the longevity of the NIF optics; but it is also important to the wavefront performance of the far-field (FF) beam. The function of the deformable mirror is to counter residual low-order FF aberrations and amplification induced FF wavefront errors.

Determining the real-ray RP location and adjusting for it is one of the two aspects of the astigmatism problem. The amount of axial astigmatism is also critical for both uncertainty reasons and PIIM. The astigmatic foci split (spread) is of the amount of astigmatism. The real-ray midpoint definition of the RP location allowed for a way to position

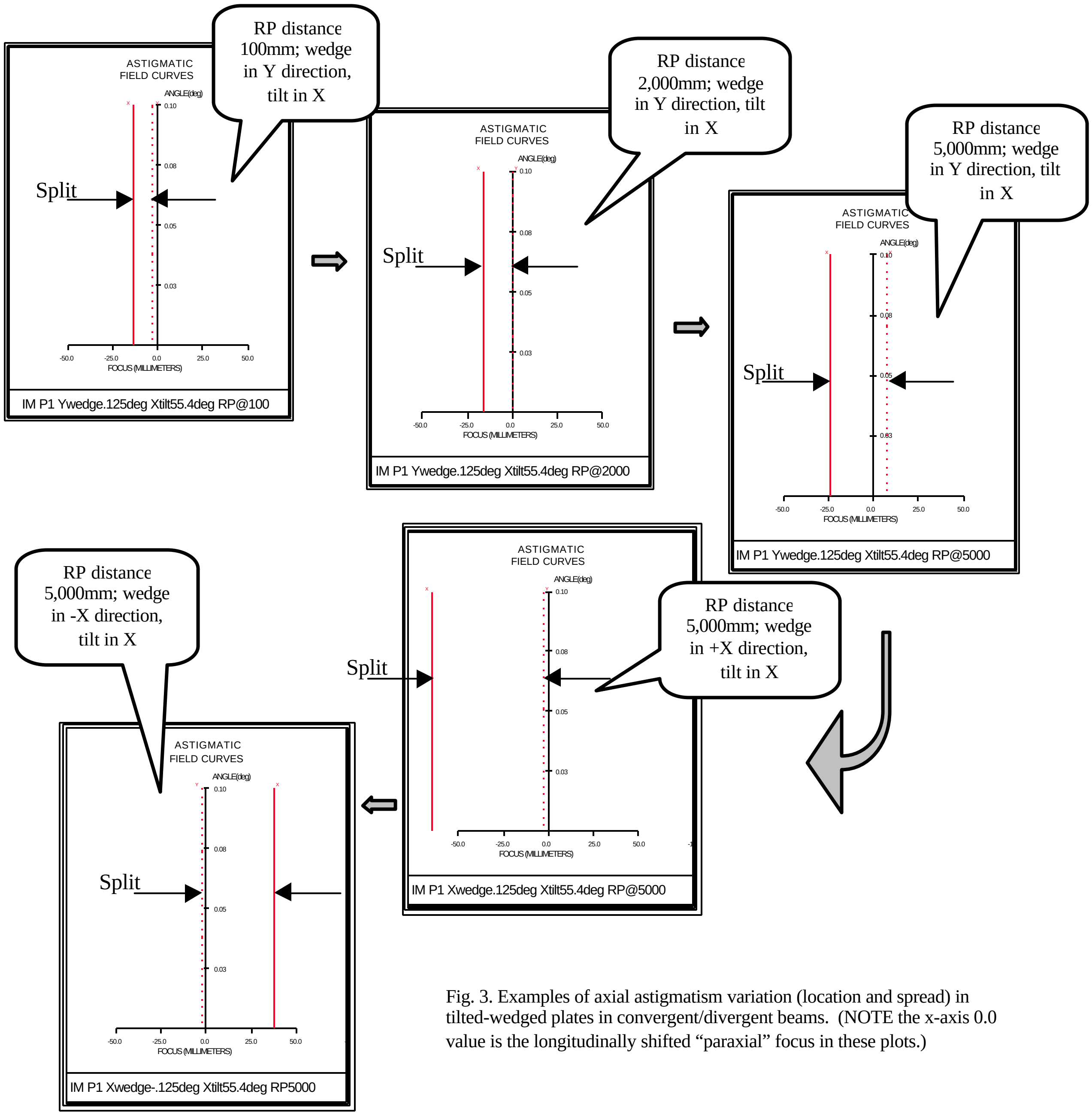


Fig. 3. Examples of axial astigmatism variation (location and spread) in tilted-wedged plates in convergent/divergent beams. (NOTE the x-axis 0.0 value is the longitudinally shifted "paraxial" focus in these plots.)

RP on the deformable mirror, but this adjustment does not reduce the amount of astigmatism.

The axial astigmatism spread is quantified at the same time the RP locations are determined. The only variables available for mitigating the magnitude of the axial astigmatism are wedge orientations. The initial evaluation of the NIF RP axial astigmatism revealed that it took up nearly the entire RP uncertainty budget. A new orientation combination of tilted-wedged plates was found that reduces the axial astigmatism by a factor of 10. Further investigations on axial astigmatism are ongoing.

Summary

Real-ray tracing is more representative on NIF than paraxial ray tracing when determining astigmatic RP locations. The determination of the NIF real-ray RP disposition required evaluating the RP imagery throughout a NIF beamline. Mitigating this situation was made possible by being able to ray trace an integrated model of a whole NIF beamline with real rays.

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.